ASTROBIOLOGY AND THE BASALTIC PLAINS IN GUSEV CRATER. D. J. Des Marais[1], B. C. Clark[2], L. S. Crumpler[3], J. D. Farmer[4], John P. Grotzinger[5], Larry A. Haskin[6], Andrew H. Knoll[7], Geoffrey A. Landis[8], Jeffrey Moersch[9], Christian Schröder[10], Thomas Wdowiak[11], Albert S. Yen[12], Steven W. Squyres[13], and the Athena Science Team, [1]MS 239-4, NASA Ames Research Center, Moffett Field, CA 94035, USA (David.J.DesMarais@nasa.gov), [2]Lockheed Martin Corporation, Littleton, CO 80127, USA, [3]New Mexico Museum of Natural History and Science, Dept. Geological Science, Albuquerque, NM 87104-1846, USA, [4]Arizona State University, Dept. of Geological Sciences, Tempe, AZ 85287-1404, USA, [5]Massachusetts Institute of Technology, Dept. of Earth, Atmospheric & Planetary Sciences, Cambridge, MA 02139, USA, [6]Washington University, Dept. of Earth & Planetary Sciences, St. Louis, MO 63130, USA, [7]Harvard University, Botanical Museum, Cambridge, MA 02138, USA, [8]NASA Glenn Research Center, Cleveland, OH 44135, USA, [9]University of Tennessee, Dept. of Earth & Planetary Sciences, Knoxville, TN 37996-1410, USA, [10]Johannes Gutenberg-Universität, Institut für Anorganische und Analytische Chemie, D-55099 Mainz, Germany, [11]University of Alabama at Birmingham, Dept. of Physics, Birmingham, AL 35294, USA, [12]Jet Propulsion Laboratory, Pasadena, CA 91109, USA, [13]Cornell University, Dept. of Astronomy, Ithaca, NY 14853, USA.

Introduction: This report assesses the availability of nutrient elements, energy and liquid water on the plains surrounding Columbia Memorial Station by evaluating observations by the MER rover Spirit in the context of previous Mars missions, Earth-based studies of martian meteorites and studies of microbial communities on Earth that represent potential analogs of martian biota.

Availability of key nutrient elements: The compositions of Gusev basalts [1] resemble those of olivine basalts beneath the seabed on Earth that deep drilling has shown to support life. Of particular relevance to biology, phosphate abundances are much greater in Gusev basalts (0.84$\pm$0.07 wt. % P_2O_5 [1]) than in oceanic basalts (typically 0.06 wt. %).

The atmospheric abundances of N_2 (~0.2 mbar) and CO_2 (~7 mbar) on Mars probably represent only a small fraction of the total global inventories that once existed. Much of the initial endowment of nitrogen has either escaped to space or has been buried as nitrates within the regolith or as ammonium ion that has substituted for cations such as K^+ in phyllosilicates.

Energy for biosynthesis and metabolism. Habitable environments must provide, at least intermittently, sources of energy to fuel metabolism and self-replication, and repair cellular constituents. Photosynthesis has long dominated global primary production on Earth, but the surface environment of Mars is exceedingly harsh. Within Gusev crater, impacts and aeolian activity have reworked ancient basalts in a surface environment that has been dominated by dry and desiccating conditions for billions of years [2].

Even in the absence of light, chemoautotrophic microorganisms can exploit oxidation-reduction reactions to obtain energy. For example, the oxidation of Fe^{2+}, Mn^{2+} and S species provides energy and reducing power for metabolism and organic synthesis. These reduced species and their oxidized alteration products have been documented in martian meteorites. In continental basaltic terrains on Earth, subsurface communities dominated by methanogenic archea obtain their energy and reducing power from H_2 and CO_2 that is generated by hydrothermal activity [3].

The aqueous alteration of ultramafic rocks produces H_2, a near-universal source of energy and reducing power for microorganisms. Below 250^o C, olivine and water react to form serpentine and brucite. If Mg and Fe are partitioned so that the chemical potentials of MgO and FeO are the same in both serpentine and brucite, magnetite and H_2 are produced. Serpentinization reactions also cause rock volumes to expand and propagate rock fractures, which allows invading waters to continue to react with olivine and other reduced minerals.

Martian igneous rocks exhibit a broad range of silica and olivine abundances that broadly overlap compositions of mafic and ultramafic rocks on Earth, including rocks that have been shown to sustain subsurface microbial communities. Three Gusev basalts have olivine abundances that lie near middle of this range of abundances [4]. Gusev basalts also contain magnetite and show evidence of at least limited chemical alteration [4]. Although magnetite can occur solely from igneous processes, it also might indicate that olivine was altered to form serpentine, magnetite and H_2.

Liquid water. The minimum water activity that is necessary to sustain microbial processes is ~0.75 for haloarchea in NaCl brines and ~0.61 for fungi in high sugar media [5] (distilled water has an activity of 1.00). But these remarkable organisms belong to derived clades that appeared relatively late in the history of microbial diversification; they are descended from organisms that do not exhibit comparable ability to function at low water activities.

Organisms can remain viable but dormant for extended periods at even lower water activities, but they must become active periodically to repair cellular damage caused by environmental agents.

Evidence for the former presence of liquid water has emerged from analyses of materials in the basaltic plains. Soils typically have surface crusts a few mm thick beneath thin dust covers [6]. Near the lander, Spirit examined a crust composed of aggregates of particles, possibly of dust size, that form porous three-dimensional structures which in some cases may have hollow, tube-like geometry at the mm scale. Similar capillary networks occur within highly evaporitic terrestrial playa settings, but their formation requires only very limited water activity that is insufficient to sustain metabolism. Soil crust processes might be active on light/dark to seasonal time scales (~0.01 to >1 yr).

Laguna Hollow is a shallow impact crater that has been filled relatively recently with fine-grained deposits. A trench revealed a mixture of silicate and soluble salt constituents that are uniform with depth [7]. If water had percolated through this deposit since it formed, the water would have preferentially mobilized soluble salts and created variations in their abundances with depth. The deposition and storage of these deposits occurred under dry conditions. Habitable conditions very likely never developed within this fill since it and perhaps other such deposits were emplaced in recent shallow impact craters in Gusev.

Spirit excavated two trenches (“Big Hole” and “The Boroughs”) in flat terrane that was remote from larger craters and had lower contents of recent coarse ejecta. Soil horizons within these inter-crater plains materials thus developed over longer periods than soil horizons in ejecta blankets and small impact-generated hollows. Abundances of S, Mg, Cl and Br varied with depth in the “Big Hole” and “The Boroughs” trenches [7], indicating that water probably percolated through these soils. However, whether the water activity of these fluids was high enough to sustain life is uncertain.

Features inside basalts, such as fracture and vug fills, might be almost as old as the basalts themselves. Given the great age inferred for the Gusev plains landscape [2], these basalts might have formed 10^8 to10^9 years ago. Brief intervals of aqueous activity might have weathered rock surfaces and deposited minerals in vugs and cracks [7]. But the bulk elemental abundances of these rocks resemble those of unaltered olivine basalts, so altering fluids did not mobilize even the most soluble alteration products [7]. Thus water/rock values were low, fluid movements were minor, thus it seems unlikely that these rock interiors could have sustained life.

A few rocks on the Gusev plains exhibited exfoliation and case hardening, features indicating extensive chemical alteration. The compositions of these rocks were not determined because they were found in images retrieved from Spirit after it had departed the area. Perhaps higher water/rock values were attained intermittently in the near subsurface.

Potential for habitable environments at Gusev crater. The dry and cold climate of Mars is due in part to the planet’s current obliquity of 25.19^o. This is far from 41.80^o, which the most probable value over the long term [8]. Dramatic increases in summer insolation can create dynamical instabilities in the polar caps that can drive atmospheric humidity levels to as much as 50 times the present level [8]. Quick disappearance of polar caps over some obliquity cycles can create surface ice in equatorial areas [9]. During earlier periods when the obliquity of Mars was high, basal melting of snow/ice deposits might have recharged subsurface aquifers in Gusev crater. Also, transient increases in atmospheric density associated with large, sustained volcanic eruptions may have permitted liquid water to be stable near the surface. Aquifers that were periodically recharged might have sustained habitable conditions for geologically long periods of time [10].

Because mafic and ultramafic terrains exhibit the potential to sustain chemosynthetic microorganisms in subsurface environments, these terrains merit closer scrutiny in future orbital and landed missions.

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